Reviewer Comments (in black**), our response (**in blue**) and revised manuscript passages** (in dark orange**)**

Reviewer 2:

In this paper the authors analyzed the geologic and vegetation control on deep and shallow landslides in the scarplands of Southern Germany. Their objective was to understand geologic conditions and the role forest management might play in helping slope stability, especially when these slopes face changing vegetation and hydrologic conditions in a changing climate.

The interplay between vegetation and sub-surface conditions to better understand regional landslide hazards is a long-studied and important topic of interest. This paper presents many useful datasets from Northern Bavaria (e.g. ERT data for several large landslides, root strength from Scots Pine, detailed landslide mapping, and soil strength properties). However, the paper would greatly improve with a more clearly defined hypotheses and motivation, which are then justified by the data and the discussion. As written, this is almost two papers: 1) about rooting strength and controls on recent shallow landsliding, and 2) about modelling the unique scarpland geology that leds to pervasive large, deep landslides that are now seemingly stable.

The reviewer is right, we failed to explain sufficiently our motivation and why we investigate both deep-seated and shallow landslides. We adapted the abstract, introduction and discussion. We present from the start of the manuscript on what the differences between deep-seated and shallow landslides are and on what time-scales these processes occur. On geological time scale, scarpland formation with alternating sedimentary layers precondition deep-seated landslides as high-strength layers overlay weak sedimentary layers. Fluvial erosion prepared deep-seated landsliding by exposing the weak layers and the landslides were caused by different potential triggers. The landslide processes changed topography (e.g. slope angle) and resulted in sheared material. On present-day scale, the deep-seated landslides set the framework for current landslide processes. These include a re-activation of deep-seated landslides or shallow landsliding on top of the deep-seated landslides. The shallow landsliding is controlled by vegetation especially root cohesion. The root cohesion is influenced by the soil thickness affecting root area ratio, which is controlled by geologic conditions. The upper hillslopes consist of Rhätolias which weathered into sandy permeable soil underlying by unweathered sandstone that restrict root depth to the upper 0.5 m. In the lower part of hillslopes, Feuerletten are abundant and soils are low permeable clay that induced wet conditions and, therefore, limited rooting depth. The sedimentary layering of the scarplands controls how vegetation affects hillslope stability and shallow landsliding. In summary, geology controlled past deep-seated landsliding that was involved in the formation of scarplands and controls present-day deep-seated and shallow landsliding. To highlight this interaction, we assessed both landslide types in one paper rather than two papers addressing each type individually.

A few major comments:

Abstract – This does not flow well and lacks a clear framing of the authors' hypotheses. The abstract mentions many methods but it is not clear how all these methods intersect.

The reviewer is correct. To improve the motivation and clarify the use of methods, we rewrote the abstract. New abstract: "Landslides are important agents of sediment transport, cause hazards and are key agents for the evolution of scarplands. Scarplands are characterized by high-strength layers overlying low-inclined landslide-susceptible layers that precondition and prepare landsliding on geological time scales. These landslides can be reactivated and their role in past hillslope evolution affected geomorphometry and material properties that set the framework for present-day shallow landslide activity. To manage present-day landslide hazards in scarplands, a combined assessment of deep-seated and shallow landsliding is required to quantify the interaction between geological conditions and vegetation that control landslide activity. For this purpose, we investigated three hillslopes affected by landsliding in the Franconian scarplands. We used geomorphic mapping to identify landforms indicating landslide activity, electrical resistivity to identify shear plane location and a mechanical stability model to assess the stability of deep-seated landslides. Furthermore, we mapped tree distribution, quantified root area ratio and root tensile strength to assess the influence of vegetation on shallow landsliding. Our results show that deep-seated landslides incorporate rotational and translational movement and suggest that sliding occurs along a geologic boundary between permeable Rhätolias sandstone and impermeable Feuerletten clays. Despite low hillslope angles, landslides could be reactivated when high pore pressures could develop along low-permeable layers. In contrast, shallow landsliding is controlled by vegetation. Our results show that rooted area is more important than species dependent root tensile strength and basal root cohesion is limited to the upper 0.5 m of the surface due to geologically controlled unfavourable soil conditions. Due to low slope inclination, root cohesion can stabilize landslide toes or slopes undercut by forest roads, independent of potential soil cohesion, when tree density is sufficient dense to provide lateral root cohesion. In summary, geology preconditions and prepares deep-seated landslides in scarplands, which set the framework of vegetation-controlled shallow landslide activity."

Introduction – The end of the introduction seems to describe the overall motivation (looking at role of vegetation on low slopes with landslides) that should be made clear much earlier and returned to throughout. For this section, I suggest shortening the forestry summary and expanding on the scarpland morphology and differences between shallow/deep landslides to introduce your hypotheses. With a clear motivation and hypotheses, the methods can then be justified.

Additionally, the paper would be strengthened by describing the different timescales of interest (e.g. recent land-use/forestry management and shallow landslides, longer-term climate shifts possibly leading to reactivation or initiation of deep landslides, timing of original (now "fossil") landslides).

We followed the recommendations of the reviewer and rewrote large parts of the introduction. We introduced the differences between deep-seated and shallow landslides and different timescales from the beginning on, shortened the forest summary and expanded scarpland morphology: "Landslides are important agents of sediment transport, cause hazards and are key agents for the evolution of scarplands. On geological scale, sedimentary deposition in terrestrial or marine environments resulted in alternating layers of different rock strength with varying inclination (Duszyński et al., 2019), which preconditions slope stability (McColl, 2022). Horizontal layering promotes the formation of plateaus, while tilted layers create cuestas (Young et al., 2000; Duszyński et al., 2019). Due to the differences in rock strength and resulting different efficacy of erosive processes, scarplands are characterized by high-strength layers overlying weaker sedimentary layers (Duszyński et al., 2019). Tectonic processes can increase slope height or slope steepness and erosion (e.g. by rivers) can undercut hillslopes and expose weaker sedimentary layers, which act as potential failure surfaces, and, thereby prepare landslide processes (McColl, 2022). Landslides can be caused by a wide range of triggers including e.g. rapid increase in pore water pressure by rainfall and/or snowmelt, loading of slope by precipitation or vegetation (McColl, 2022). The tilting of sedimentary layers controls the landslide type in scarplands. On frontscarps, sediment layers dip into the slope (Duszyński et al., 2019) and landslides in form of rockfall (e.g. Glade et al., 2017) or deep-seated landslides (e.g. Jäger et al., 2013) are abundant. In contrast, sedimentary layers dipping out of the slope characterize backscarps (Schmidt and Beyer, 2003; Duszyński et al., 2019), where landsliding processes comprise cambering (Hutchinson, 1991), block gliding (Young, 1983), lateral spreading (Spreafico et al., 2017) or deep-seated sliding processes (Pain, 1986; Schmidt and Beyer, 2003). Geologic conditions precondition landsliding and the formation of scarplands on geological scale. On present-day, reactivation of deep-seated landslides by geomorphic and anthropogenic processes (McColl, 2022) cause hazards to communities living in scarplands (Thiebes et al., 2014; Wilfing et al., 2018), therefore, an understanding of geologic controls on landsliding is required to analyse slope stability for hazard management.

As deep-seated landslides were important in shaping scarplands, they changed the geomorphometry of hillslopes (e.g. inclination) and sheared material and, therefore, precondition and prepare present-day shallow landslides. Shallow landslides are characterized by soil material <2 m deep moving downslope in a flowing, sliding or complex type of movement (Sidle and Bogaard, 2016; Vergani et al., 2017). Forests can affect shallow landsliding mechanically and hydrologically (Vergani et al., 2017). They can reduce soil moisture by interception and evaporation, suction and transpiration as well as infiltration and subsurface flow (Sidle and Bogaard, 2016; Vergani et al., 2017). Mechanically, forests can reinforce soil by roots (Wu, 1984; Phillips et al., 2021), roots and stems can induce buttressing (Vergani et al., 2017) and anchoring and trees can increase normal force on slopes (Ziemer, 1981; Terwilliger and Waldron, 1991; Selby, 1993; Schmidt et al., 2001; Roering et al., 2003). In forest management, the protective function of forests has been considered for a long time in high mountain regions (Dorren et al., 2005; Bischetti et al., 2009). However, forestry is not only affected by landslide activity, which causes damage to roads and loss of timber (Sidle and Ochiai, 2006), but also has a considerable impact on slope stability through changing the characteristics of forests in sliding-prone areas (Phillips et al., 2021). Root reinforcement of slope stability declines after logging operations (Ziemer, 1981; Schmidt et al., 2001; Vergani et al., 2017) and forestry roads enhance landsliding through undercutting slopes (Borga et al., 2005; van Beek et al., 2008). Changes in tree species composition and tree density have also an impact on the root reinforcement in forests (Roering et al., 2003; Genet et al., 2008). The influence of vegetation on landslides has been intensely studied on steep slopes in the European Alps (Bischetti et al., 2009; Vergani et al., 2014), the Oregon Coast Range (Schmidt et al., 2001; Roering et al., 2003), Southern California (Terwilliger and Waldron, 1991), Northern Italy (Borga et al., 2005; Schwarz et al., 2010b), New Zealand (Giadrossich et al., 2020) or China (Genet et al., 2008), however, little effort was conducted to understand the influence of vegetation on landsliding on lower-inclined hillslopes such as scarplands in Southern Germany (e.g. Thiebes et al., 2014) or in the Flemish Ardennes (e.g. Van Den Eeckhaut et al., 2009), where geologic conditions such as clay layers enable landsliding (Skempton, 1964; Chandler, 2000; Bromhead, 2013).“

We rewrote the motivation to clarify what are the objectives of the paper and why we investigate different landslide types: “As geological conditions control deep-seated landslide activity on geological scale that set the framework for shallow landslides in scarplands on present-day scale, there is a need to understand how landslide historicity affects current deep-seated and shallow landslide activity. As climate change affects forests (e.g. Seidl et al., 2017) and alters landslide activity (e.g. Crozier, 2010), combined forestry management and hazards approaches on shallow landslides (Phillips et al., 2021) should be extended by incorporating geological controls in scarplands. In this study, we aim to (1) quantify the relation between deep-seated landslides and geology in the Franconian Alb and estimate if landslides can be reactivated by hydrologic conditions. For this purpose, we extended a landslide inventory and compared landslide occurrence to geology. On three landslides, we applied electrical resistivity tomography (ERT) to identify shear plane depth and modelled hillslope stability with different water level scenarios. Furthermore, we (2) test if vegetation-induced root cohesion can stabilize shallow landslides occurring on deep-seated landslides. For this reason, we mapped tree distribution, quantified root cohesion and applied a slope stability model. Our results aim to improve forest management practices to reduce landslide occurrence in the Franconian Alb."

Discussion – As written, this section seems to raise more questions than it answers. For example, why such a focus on tree roots when the landslides analyzed are much much deeper than the rooting depth? Or, for stability modelling, why not model the geologic and hydrologic conditions needed for the original failures to test the importance of scarpland geology (e.g. Perkins et al., 2017)? This section could be strengthened by clearly describing: what is novel from this study, how low angle hillslopes compare to steep vegetated hillslopes, and intersection of geology and deep landslides with vegetation and shallow landslides.

Thank you for these valuable comments. The model approach by Perkins et al. (2017) combining the landslide stability model Scoops3D with the hydrological model VS2Dt sounds really interesting and would be suited if we want to model more accurately landslide stability of deep-seated landslides maybe in a future manuscript. From our point of view, a new model approach would not provide any more valuable information for this paper, as the purpose of this paper is a different one. We want to incorporate as well the geological control on current shallow landslides affected by vegetation. As the reviewer commented correctly in previous comments, we failed to provide a clearer motivation and, therefore, we revised the abstract and introduction to clarify our motivation and used set up. We revised the discussion section to clarify what is novel of our paper. In the first section of the discussion, we focus on geologic control on deep-seated landsliding. We revised the section on the role of deep-seated landslides for scarpland formation:
"The combination of high-permeable Rhätolias above Feuerletten controls deep-seated landsliding. Of the 125 observed landslides in our research area, 95 % occurred at the Rhätolias-Feuerletten boundary (Fig. 2b), which suggests that Feuerletten play a key role in landsliding. The Feuerletten possess a lower angle of internal friction than Rhätolias (Table 1) and cohesion of these clays is susceptible to saturation. Previous landslide inventories of the Franconian Alb support this role of Feuerletten in the North-Bavarian scarplands, where Feuerletten were responsible for an inappropriate high proportion of landslides (Kany and Hammer, 1985). Kany and Hammer (1985) assumed that most landslides were fossil and occurred under past climatic conditions, however, they suggested that these deep-seated landslides could be reactivated due to anthropogenic impacts as road cutting and forestry. The observed movement of the Thurnau landslide affecting the highway (Fig. 2b; Wilfing et al., 2018) supports the argument of potential reactivation."

We clarified the purpose of the application of the ERT and what was the major outcome: "The ERT enabled the identification of the shear plane location and suggested that landslides are complex with rotational and translational movement. The Putzenstein landslide revealed a hummocky topography (Fig. 3a) and the ERT showed three high-resistivity cells with resistivities up to 4,000 Ohm m and a thickness between 7 and 18 m located above low-resistivity bodies at transect length between 5 and 70 m, 70 to 195 m and 232 to 315 m (Fig. 5a). Pürckhauer drillings revealed fine and silty sand in the upper 1 m. We interpret these cells as dry Rhätolias above wet Feuerletten. The form of these cells and the hummocky topography indicate three rotational slabs. In between the lower high-resistivity cells, low resistivities indicate a water-saturated rotational slab (Fig. 5a). The lower part of the landslide was characterized by a flat topography, low-resistivity areas, and near-surface clay material. Therefore, we interpret this landslide part as a translational slide within the Feuerletten. The Weinreichsgrab landslide revealed a similar pattern of three high-resistivity cells within hummocky terrain with near-surface silty sand followed by flat terrain with low resistivities and near-surface clay (Fig. 5b). These results indicate three rotational slabs and one translational slab at the toe of the landslide. In contrast, the Fürstenanger landslide showed one high-resistivity area in the upper part indicating a rotational failure (Fig. 5c). However, the major part of the landslide showed heterogeneous near-surface resistivities underlain by low resistivities in form of a straight slope indicating a translational landslide. The observed resistivity pattern was disturbed at 180 m transect length, where areas of higher resistivities dipped 45° into the slope resulting in a 10-12 m thick zone of contrasting low and high resistivities (Fig. S3 k). However, the topography showed no evidence of a rotational slide, therefore, we interpret the resistivity pattern as an artefact of the measurement rather than an indicator for rotational movement. In summary, electrical resistivity tomography enabled in most conditions the identification of the shear plane due to high resistivity contrasts between Rhätolias and Feuerletten with an uncertainty depending on the resolution of the tomography in the range of 2.5 m. Therefore, we established minimum, mean and maximum shear plane depth scenarios to propagate the uncertainty into our stability analysis. All shear plane scenarios showed a shear plane location far below rooting depth of trees observed on the landslides indicating that root cohesion by trees plays no role in stabilisation of deep-seated landslides."

We discussed the different landslide stability scenarios, how the variation of material properties results in differences of stability assessment that complicates the interpretation: "Reactivation of deep-seated landslides depends on cohesion and water saturation. As soil cohesion showed a large variation between individual layers and within each layer of the Feuerletten (Table 1; Boley Geotechnik, 2018; Wilfing et al., 2018), we used three different cohesion scenarios in combination with the residual internal angle of friction of 8.4° measured by Boley Geotechnik (2018) for the stability analysis. Our landslide stability analysis showed that all three landslides revealed stable conditions independent of saturation with FoS values above 1.66 when assuming a soil cohesion of 28.6 kPa (Fig. 9). This high cohesion is the mean soil cohesion of soft silty Feuerletten clay (Table 1) and potentially representative for undisturbed Feuerletten. According to laboratory tests by Ikari and Kopf (2011), soil cohesion can re-develop in clays after landsliding due to normal stress. To include this scenario, we used a reduced soil cohesion of 8.6 kPa (1/3 of the original value). When assuming a residual cohesion, an FoS below 1 is not reached at Putzenstein landslide independent of water level (Fig. 9a), at Weinreichsgrab below saturation of 0.8 in the upper slice height scenario (Fig. 9b) and at Fürstenanger below 0.8 for the maximum and 1.0 for the mean shear plane scenario (Fig. 9c). The development of high saturation in the sand layers of Rhätolias is unlikely as sand is very permeable. However, Rhätolias has impermeable clay layers (Boley Geotechnik, 2018) and tectonic-induced fractures can increase water infiltration through these clay layers (Wilfing et al., 2018). Therefore, water can be trapped between clay layers in Rhätolias and clay layers in underlying Feuerletten, which can cause hydrostatic pressures equal to high saturation levels (Rogers and Selby, 1980; Selby, 1993). Therefore, a reactivation of the entire landslide could be possible due to the geologic conditions of alternating clay layers within the Rhätolias underlain by impermeable Feuerletten. Assuming no residual soil cohesion as suggested by Skempton (1985), the Fürstenanger landslide would be instable independent of saturation level and shear plane scenario (Fig. 9b-c), while the Putzenstein and Weinreichsgrab landslide would get instable between a saturation level of 0.65 to 1.0 and 0 to 0.5 depending on shear plane scenario (Fig. 9a-b). However, there are no indicators for a reactivation of the Fürstenanger landslide while recent fissures indicate potential reactivation of Putzenstein and Weinreichsgrab landslides (Fig. 3a-b). The applied model scenarios showed a large variation of stability states depending on chosen soil cohesion and water availability. The application of landslide models incorporating hydrological conditions (e.g. Perkins et al., 2017) can improve the assessment of slope stability."

In the second section, we focused on vegetation control on shallow landsliding. We highlighted first the role of root area ratio and tensile strength: "Root area ratio plays a more important role in stabilisation of shallow landslides than tensile strength. Based on 27 tests, we developed a tensile strength root diameter relationship for Scots pines, which is characterized by an exponential decrease of tensile strength with increasing root diameter (r^2=0.55; Fig. 6). Therefore, relative tensile strength increases with decreasing root diameters (Stokes et al., 2009) as thinner roots possess a higher cellulose content that provides additional strength (Genet et al., 2005). The power law and the statistical degree is in the range of previous measurements on European beeches and Norway spruces (Fig. 6; Genet et al., 2005; Bischetti et al., 2009) and show only little difference between species (Genet et al., 2005; Hales, 2018). Our RAR measurements revealed two times higher RAR values for European beeches than Scots pines or Norway spruces (Fig. 8a-c). Consequently, root cohesion is much higher for European beech than Scots pine and Norway spruce (Fig. 8d-f). A decrease in tree species number of Scots pine and Norway spruce with an increase of European beech as planned by the forest management (personal communication by F. Maier) would increase the root cohesion and therefore slope stability."

Afterwards, we discussed the role of geology on soil thickness and rooted depth: "Local soil conditions are controlled by geology and geologically affected soil conditions at hillslope scale reduce rooting depth (Fig. 1). Our RAR measurements showed that roots were restricted to the upper 0.5 m for Scot pines and Norway spruces and to 0.4 m for European beeches (Fig. 8a-c). Within a species, RAR revealed no differences between topographic locations at the slope or between Rhätolias or Feuerletten. The rooting depth was very low compared to pines and beeches occurring in the near-by Frankenwald that showed rooting depth up to 1.2 m (Nordmann et al., 2009), however, lithology and soil conditions are different, which seem to influence root properties more than species identity (Lwila et al., 2021). At upper slope location, Rhätolias is abundant and characterized by high permeable sandy soil (Fig. 1b). In dry soils, trees usually develop deeper roots to reach groundwater (Hoffmann and Usoltsev, 2001), however, the hard sandstone layers within the Rhätolias prevent deeper rooting (Fig. 1b). In addition, sandy soils are less deeply warmed than fine-grained soils which results in shallower root growth (Kutschera and Lichtenegger, 2002). At lower slope locations, clayey Feuerletten are abundant (Fig. 1c) which resulted in combination with slope-induced water flow in moist conditions. Moist aerated soils are characterized by extreme flat rooting (Stone and Kalisz, 1991; Kutschera and Lichtenegger, 2002). Therefore, lithology and associated soil conditions in combination with topography-controlled water flow resulted in low rooting depth. Consequently, basal root cohesion can only effect shallow landslides with a shear plane below 0.4 or 0.5 m depth, respectively."

We rewrote the section how root cohesion influences the stability models and better connected our stability models to landslide activity observations: "Tree density plays an important role in shallow landslide stabilisation by controlling lateral root cohesion. Tensed roots at Putzenstein (Fig. 4a-c) and bent or tilted trees at Weinreichsgrab (Fig. 4f) indicate soil creep or shallow landsliding in the upper 1 to 1.5 m of Feuerletten clay (Fig. 3a-b). To quantify the minimum root cohesion necessary to stabilise low-inclined slopes, we tested shallow landsliding with shear planes up to 1.5 m depth for slopes affected by forest road cuts and at landslide toes with clay material near the surface enabling high saturation (m=1). Slopes above forest road cuts were characterized by low inclination between 11 and 12°, while landslide toes revealed even lower slope angles in the range of 6 to 9°. Assuming a shear plane depth of 0.3 m, slopes above road cuts and landslide toes would require a cohesion between 0.2 and 0.8 kPa (Fig. 10) to stabilize the slope. As root cohesion of Norway spruce, Scots pine and European beech between 0.3 and 0.4 m depth is above 1 kPa (Fig. 8d-f), root cohesion would be sufficient to stabilize the slope. However, species distribution, number and position have an influence on the occurrence of landslides (Roering et al., 2003), as the vegetation patterns always leave gaps with lower root cohesion. Our investigated slopes above road cuts were characterized by a combination of European beech and Norway spruce at Putzenstein and Weinreichsgrab landslides (Fig. 6a-b), which grew dense enough to provide sufficient root cohesion to stabilize the slopes. Dense thickets of

Norway spruce occurred on Fürstenanger slopes above road cuts and on all landslide toes (Fig. 6c) and provide high root density that would enable sufficient stabilization. When shear planes exceed rooting depth, lateral root cohesion can have a stabilizing effect (Schwarz et al., 2010b) by affecting the onset and size of shallow landsliding (Schmidt et al., 2001; Roering et al., 2003) as indicated by tensed roots observed at Putzenstein (Fig. 4b). To stabilize shallow landslides with shear planes up to 1.5 m, our calculations showed that a cohesion between 1 and 4.5 kPa would be required (Fig. 10). As lateral root cohesion is the sum of root cohesion of rooted depth, all three investigated species would provide sufficient lateral root cohesion to stabilize the slope (Fig. 8d-f) independent of potential soil cohesion, when spacing of trees enable an entire cover of the slope. Sufficient tree cover is provided at landslide toes and at the slope above the road cut at Fürstenanger (Fig. 6c), where thickets of Scots pine are abundant. Above road cuts at Putzenstein and Weinreichsgrab, European beeches occur that provide the highest calculated root cohesion (Fig. 8f). Our analysis excluded dead or harvested trees that can provide additional root cohesion until they rot away (e.g. Ammann et al., 2009; Vergani et al., 2017), therefore, we eventually underestimate both basal and lateral root cohesion. Despite the calculations suggest that lateral root cohesion should prevent shallow landsliding, tilted and bent trees especially at Weinreichsgrab (Fig. 4f) indicate the occurrence of soil creep and potential slow shallow landslide movement (Van Den Eeckhaut et al., 2009; Pawlik and Šamonil, 2018).“

We moved the forestry management to an additional chapter called “Potential impacts of forestry activity on future shallow landsliding”.

Specific comments:

ABSTRACT

13: does low slope refer to the geologic contact or hillslope angle (likely hillslope, but confusing after talking about dipping angles)? Does high pore pressure refer to a measured, modelled, or inferred point?

AND

14: geologic conditions should be hydrologic

AND

18: why is European beech specifically helpful to landslide stability? If making this recommendation, include results leading to this conclusion.

We rewrote the abstract. We reshaped the sentence on used techniques and from the revised sentence it should be clear that we did not measure any pore pressures: ”For this purpose, we investigated three hillslopes affected by landsliding in the Franconian scarplands. We used geomorphic mapping to identify landforms indicating landslide activity, electrical resistivity to identify shear plane location and a mechanical stability model to assess the stability of deep-seated landslides. Furthermore, we mapped tree distribution, quantified root area ratio and root tensile strength to assess the influence of vegetation on shallow landsliding.” Furthermore, we changed “slope” to “hillslope angle” to clarify that we are not referring to dipping angle of the sedimentary layers. In addition, we followed the comment of Reviewer 1 and substituted “geological conditions” with “along low-permeable layers”. New sentence is: Despite low hillslope angles, landslides could be reactivated when high pore pressures could develop along low-permeable layers.”

INTRODUCTION:

24: “sedimentary origin” should be specified as “scarplands”

AND

24-25: jump into very detailed geology and landslide classifications without setting up overall objectives

We rewrote the entire section of the introduction section and explained in more detail how scarpland formation or properties precondition and prepare deep-seated landslides. We also set up the objective of studying deep-seated landslide much earlier. “Landslides are important agents of sediment transport, cause hazards and are key agents for the evolution of scarplands. On geological scale, sedimentary deposition in terrestrial or marine environments resulted in alternating layers of different rock strength with varying inclination (Duszyński et al., 2019), which preconditions slope stability (McColl, 2022). Horizontal layering promotes the formation of plateaus, while tilted layers create cuestas (Young et al., 2000; Duszyński et al., 2019). Due to the differences in rock strength and resulting different efficacy of erosive processes, scarplands are characterized by high-strength layers overlying weaker sedimentary layers (Duszyński et al., 2019). Tectonic processes can increase slope height or slope steepness and erosion (e.g. by rivers) can undercut hillslopes and expose weaker sedimentary layers, which act as potential failure surfaces, and, thereby prepare landslide processes (McColl, 2022). Landslides can be caused by a wide range of triggers including e.g. rapid increase in pore water pressure by rainfall and/or snowmelt, loading of slope by precipitation or vegetation (McColl, 2022). The tilting of sedimentary layers controls the landslide type in scarplands. On frontscarps, sediment layers dip into the slope (Duszyński et al., 2019) and landslides in form of rockfall (e.g. Glade et al., 2017) or deep-seated landslides (e.g. Jäger et al., 2013) are abundant. In contrast, sedimentary layers dipping out of the slope characterize backscarps (Schmidt and Beyer, 2003; Duszyński et al., 2019), where landsliding processes comprise cambering (Hutchinson, 1991), block gliding (Young, 1983), lateral spreading (Spreafico et al., 2017) or deep-seated sliding processes (Pain, 1986; Schmidt and Beyer, 2003). Geologic conditions precondition landsliding and the formation of scarplands on geological scale. On present-day, reactivation of deep-seated landslides by geomorphic and anthropogenic processes (McColl, 2022) cause hazards to communities living in scarplands (Thiebes et al., 2014; Wilfing et al., 2018), therefore, an understanding of geologic controls on landsliding is required to analyse slope stability for hazard management.”

36: Using only a depth cutoff is a little misleading, typically shallow=landslide rooted in soil and deep=landslide rooted in rock.

We followed the reviewer’s comment and added the word soil to the definition of shallow landslides: “Shallow landslides are characterized by soil material <2 m deep moving downslope in a flowing, sliding or complex type of movement (Sidle and Bogaard, 2016; Vergani et al., 2017).” We highlighted that scarpland formation resulted in different rock layers that affect deep-seated landslides.

50: change “therefore” to “and”

This criticized sentence was deleted in the revision process.

63: If this is the motivational framework, introduce early on and include in abstract. Frame your hypotheses or research questions based on this motivation. For example, in low slope scarplands do you expect vegetation to have more or less influence than steep mountains?

We revised the motivation and framed our research questions better on the motivation: “As geological conditions control deep-seated landslide activity on geological scale that set the framework for shallow landslides in scarplands on present-day scale, there is a need to understand how landslide historicity affects current deep-seated and shallow landslide activity. As climate change affects forests (e.g. Seidl et al., 2017) and alters landslide activity (e.g. Crozier, 2010), combined forestry management and hazards approaches on shallow landslides (Phillips et al., 2021) should be extended by incorporating geological controls in scarplands. We revised our objectives to link these closer to the motivation: “In this study, we aim to (1) quantify the relation between deep-seated landslides and geology in the Franconian Alb and estimate if landslides can be reactivated by hydrologic conditions. For this purpose, we extended a landslide inventory and compared landslide occurrence to geology. On three landslides, we applied electrical resistivity tomography (ERT) to identify shear plane depth and modelled hillslope stability with different water level scenarios. Furthermore, we (2) test if vegetation-induced root cohesion can stabilize shallow landslides occurring on deep-seated landslides. For this reason, we mapped tree distribution, quantified root cohesion and applied a slope stability model. Our results aim to improve forest management practices to reduce landslide occurrence in the Franconian Alb.”

METHODS:

125-126: Studies show that significant root strength can persist for up to ~10 years (e.g. Ammann et al., 2009-Norway Spruce). What is age of trees vs. age of landslides?

The deep-seated landslides were formed probably under past climatic conditions. The shallow landslides are recent landslides and it is hard to establish an age. The trees are definitely older as they are bent or tilted or show tensed roots, which are all effects of landslide activity. We added the information of the Ammann paper to the method section: “Dead and cut trees were excluded as the influence of roots on cohesion decreases with ongoing decomposition (Vergani et al., 2014; Zhu et al., 2020) until trees rot away (Ziemer, 1981; Ammann et al., 2009).” We also added information to the discussion: “Our analysis excluded dead or harvested trees that can provide additional root cohesion until they rot away (e.g. Ammann et al., 2009; Vergani et al., 2017), therefore, we eventually underestimate both basal and lateral root cohesion.”

127: insert “…selected 15 individual free-standing…”

Done.

128: remove “at 15 trees”

Done.

182: how was this material collected? Does this include bedrock material? Or just landslide material?

The material was collected by the company Boley using 35 boreholes with between 30 and 240 m depth, in total 1700 m were drilled on landslide material and neighbouring bedrock not affected (yet) by the landslide. The aim of the investigation was to find an alternative route for the affected highway. We changed the text to: “Mechanical strength parameters of Feuerletten and Rhätolias were quantified using approximately 90 circular, direct and triaxial tests on materials derived from 35 boreholes on the Thurnau landslide affecting the highway (Fig. 2B) and surrounding bedrock (Boley Geotechnik, 2018; Wilfing et al., 2018).”

RESULTS:

119: what do you mean by “follow no expositional pattern”?

We meant that the landslides show no preference of exposition. If landslides are climatic driven such as driven by permafrost, which would be in our case more than 20,000 years ago, the landslides on south-facing slopes show usually a different pattern then on north-facing slopes. As this is not the objective of the manuscript, we deleted the part on expositional pattern.

DISCUSSION:

352-353: why not try to model this instead? Similar to Perkins et al., 2017

Thank you for this comment and the paper, which applied very interesting models. Our study focuses on field measurements with a modelling component. Applying the Scoops3D model in combination with VS2Dt model would be a very useful for future work maybe in form of PhD project. However, as the reviewer mentioned, this paper is very dense and maybe two papers and incorporating two new model approaches would completely shift the focus more to the deep-seated landslides, which is not the aim of our study. We will reframe the motivation to make this clearer.

376-377: Why such a focus on trees then? Why not focus on the mechanics of these deep landslides using stability modeling and ERT results?

The initial motivation of the study was to investigate the role of trees on landsliding and provide a recommendation on tree selection for hazard management. During our study, it became clearer that geology affects not only the deep-seated landslides but also the shallow landslides as geologic conditions influence soil and limited rooting depth in our case. We think that this is the interesting point for our study but also for scarplands. You cannot assess vegetation influence without incorporating geological conditions as geology preconditions landslides. We made this clearer in the abstract, introduction and discussion of the manuscript.

378: Where on the landslide? Just deposit/mobile material?

Both. See our detailed answer above (Response to line 182).

390-395: There are a lot of hypotheses presented here without much to back-up conclusions. Seems like the more interesting modeling problem if the authors want to understand the role of scarpland geology

Here, we disagree. We could apply a more sophisticated model as the reviewer suggested. However, the material properties vary which results in a large variation of potential stability scenarios. We could improve the hydrological part of the modelling but it will not solve the problem of constraining the material variation. We also would only investigate the role of deep-seated landslides on scarpland formation, however, or focus, which we not clearly enough explained, was how the geological framework preconditioned and resulted in deep-seated landslides that on present-day affect forestry.

426-427: what are the depths of shallow landslides occurring on these larger landslides?

We added the information to the discussion section: "Tensed roots at Putzenstein (Fig. 4a-c) and bent or tilted trees at Weinreichsgrab (Fig. 4f) indicate soil creep or shallow landsliding in the upper 1 to 1.5 m of Feuerletten clay (Fig. 3a-b)."

FIGURES:

NEW FIG(s): Suggest adding schematic of geology and/or typical slope profile, and photo of typical soil pit with roots.

Thank you for this comment. We added a geological sketch and photos of soil pits. Slope transects can be derived from the ERT transects, where topography was incorporated.

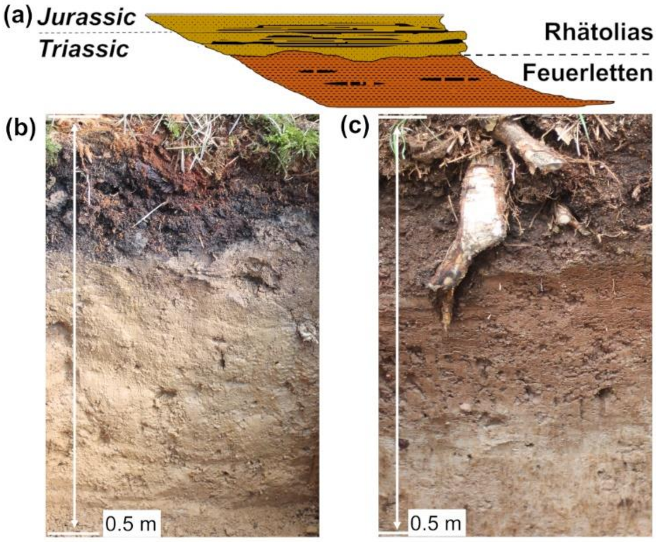
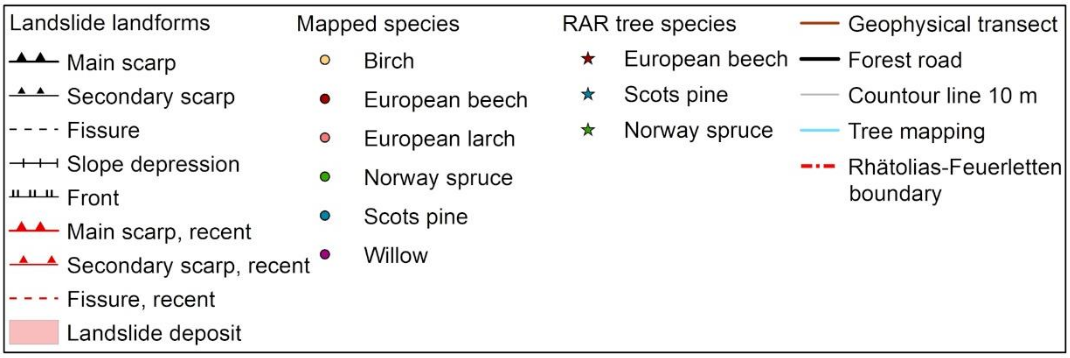


Figure 1: (a) Geological profile of investigated slopes in the Franconian Alb. Soil pits showing the upper 0.5 m of soil developed in (b) Rhätolias sandstone and (c) Feuerletten clay.

FIG 5: missing symbology

We added the symbology (see below).


Landslide landforms
Main scarp
Secondary scarp
Fissure
Slope depression
Front
Main scarp, recent
Secondary scarp, recent
Fissure, recent
Landslide deposit
Mapped species
Birch
European beech
European larch
Norway spruce
Scots pine
Willow
RAR tree species
European beech
Scots pine
Norway spruce
Geophysical transect
Forest road
Countour line 10 m
Tree mapping
Rhätolias-Feuerletten boundary